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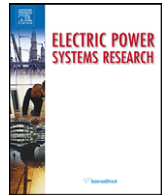
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Demand response in the UK's domestic sector

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ABSTRACT

The purpose of this paper is to assess the current level of demand responsiveness among domestic loads. The paper first studies different load profiles of domestic consumers which are composed of power consumption of end-use appliances. Afterwards, it differentiates those loads which could become responsive and evaluates the aggregated effect of these loads and the margin which could be derived from them. The area which has been considered is a residential area; consists of results have been demonstrated on a real residential network in southwest of the UK; small residential area in city of Bath.

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1. Introduction

Along with restructuring the electricity market in the UK and government's aim to draw 20% of total electricity from renewables together with reducing the carbon dioxide emissions down to 26–32% by 2020, demand side has been given a superior likelihood to contribute in attaining this target. Maintaining the security of supply is also becoming increasingly strategic issue considering both volatility of wholesale energy prices, and limited facilities for electricity generation, transmission and distribution which has resulted that suppliers becoming unable to fulfill their contractual obligations.

Domestic sector in the UK is responsible for nearly one third of electricity consumption and the related emissions into the atmosphere resulted by electric power stations. In the UK, the domestic sector is the largest contributor to winter peak demand, and growing domestic electricity demand is straining the available power generation and transmission infrastructure, and meeting the peak demands in winter is increasingly expensive and high price spikes is seen as shown in Fig. 1 [1].

Demand has been participating in improving economy, security and reliability of electricity industry as well as eliminating the environmental concerns since the beginning of introducing Demand Side Management (DSM) programs in the early 1970s. Dynamic demand (responsive demand) is one of the DSM methods which is intended to be utilized while supplying the load is either restricted

because of a network constraints or demand has exceeded over the available power. Section 18 of the Climate Change and Sustainable Energy Act [2], requires the government to report on responsive demand technologies and determines whether it is appropriate to take further action to use responsive demand technologies or not. Services which are currently provided through responsive demand require communication between load and network in order to dispatch negative load upon to network request to provide services such as spinning reserve [3], frequency control [4], short-term operating reserve (STOR) [5].

The negative aspect of current schemes for employing responsive demand is that they all consider large consumers which upon to instruction of network operator are able to reduce huge bulk of load (i.e. minimum 3 MW for STOR) and in fact small domestic demand are not able to participate in these programmes, nonetheless domestic sector accounts for 29% of total electricity consumed in the UK and loads in this sector have the capability to become responsive and if the collective-effect of responsive demand derived from residential consumers be considered it may have more advantages than current methods in particular in the UK as residential consumers are mostly located in high density areas and many issues as a result of concentration of domestic demand such as need for distribution network reinforcement, may be rectified by considering aggregated effect of responsive demand in domestic sector.

The biggest barrier in utilizing the domestic demand response is lack of information regarding the consumers' behaviour and consumption pattern. Small domestic appliances have a random operation pattern depending on the type of consumer. Studying the individual consumers' load profile is also not feasible due to the small demand level among domestic consumers. Therefore, it

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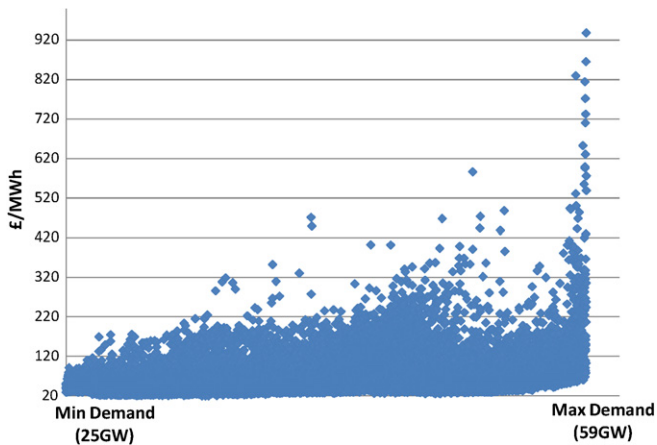


Fig. 1. Wholesale price of electricity at different demand levels.

is required to have a generalized tool which is applicable to a group of consumers. Since the aim is not to forecast the demand, but to assess the potential for demand responsiveness, such generalized tool if takes the factors which have impact on consumption pattern results in satisfactory outcome.

In this paper a generalized tool to assess the responsiveness level among domestic consumers is presented. Electricity tariffs which have impact on consumption pattern of domestic consumers are taken into account and different load profiles for different groups of consumers are studied. Then by distinguishing those loads which have the potential to become responsive through numerical example on domestic sector, total responsiveness level is assessed.

This structure of this paper is as follows: section two studies different load profiles in the UK and shows the impact of different electricity tariffs on the load profile of domestic consumers. In section three, the load profiles of domestic consumers are studied by breaking them down into the load profile of end-use appliances. In section four the responsiveness is explained and aggregated amount of all the loads which could become responsive is modelled. Finally by presenting a numerical example in a small residential area with different type of load profiles, total amount of load which could become responsive is quantified.

2. Load profile in the UK

Load profile shows the consumption pattern of power and is one of the unique characteristics of each consumer because of the dissimilarity need for power in terms of time, level depending on several factors; such as number of people living in each house; their job, age and education level, type of house, climate conditions etc. In the UK, 8 different standard load profiles have been introduced by Elexon. They are included:

1. Profile Class 1: domestic unrestricted customers;
2. Profile Class 2: domestic Economy 7 customers;
3. Profile Class 3: non-domestic unrestricted customers;
4. Profile Class 4: non-domestic Economy 7 customers;
5. Profile Class 5: non-domestic maximum demand (MD) customers with a peak load factor (LF) of less than 20%;
6. Profile Class 6: non-domestic maximum demand customers with a peak load factor between 20% and 30%;
7. Profile Class 7: non-domestic maximum demand customers with a peak load factor between 30% and 40%;
8. Profile Class 8: non-domestic maximum demand customers with a peak load factor over 40%.

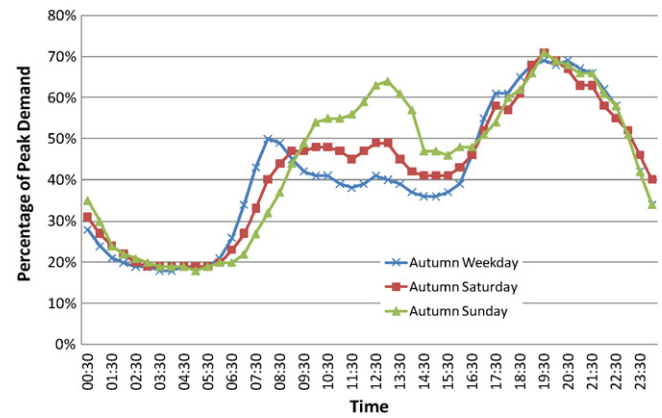


Fig. 2. Domestic unrestricted load profile.

Power consumption in particular among domestic consumers is either non-restricted or committed to some sort of demand management. DSM programmes aim to modify the load profiles of consumers in order to increase the efficiency and reliability of power systems. Some programmes directly change the load profile by installing the devices which control the power consumption of appliances such as using artificial intelligence based load control for domestic lighting. Other programmes may commit consumers to control their power consumption in return of financial incentives; time-of-use (ToU) tariffs which offers cheaper rate for power consumption during a period. ToU tariffs for households were first introduced in 1965 and led to a very important development of electric storage water heaters and the corresponding growth of off-peak consumption [6]. In the UK; Economy 7 is the well-known scheme for domestic consumers and it gives 7 h continuous low tariff power (mostly overnight) to consumers. Another scheme is called Economy 10 in which 10 h low tariff is split between day and time; usually 2 h in the morning, 3 h in the afternoon and 5 h overnight.

In 2006 16% of total domestic consumers were committed to Economy 7 tariff; this is equal to 27% of total electrical energy consumed in domestic sector [7]. The commitment level varies across the country but in general consumers save money through reducing their consumption during the day and shift their demand in off-peak hours. Figs. 2 and 3 show different types of domestic load profile for the autumn season in the UK.

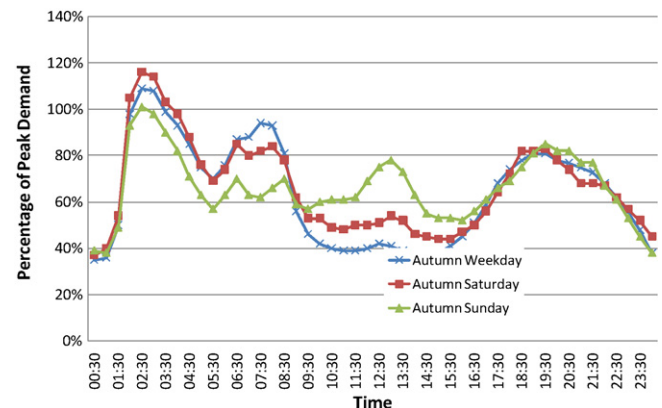


Fig. 3. Domestic Economy 7 load profile.

Table 1
Domestic load groups.

Type	Members
Cold appliances	Refrigerators: one door refrigerators with or without frozen compartment, fridge-freezers: two door combination refrigerators, upright freezers, chest freezers
Wet appliances	Washing machines: any automatic washing machine including the washing cycle of washer-dryers, tumble dryers: all types of dryers including the drying cycle of washer-dryers, dishwashers
Cooking appliances	Electric ovens: including grills electric hobs microwaves: includes combination microwave/grill/convection ovens electric kettles: includes all types of electric kettle mixer (hand mixer or stand-up mixer), hot drinks makers: coffee and tea makers, sandwich toasters pop-up toasters deep fat fryers, electric frying pans slow cookers cooker hoods, food preparation appliances: mixers, blenders, processors, whisks etc.
Lighting appliances	Incandescent: 100 W, 60 W and 40 W, tungsten halogen: an average wattage of 30 W, fluorescent strip: an average wattage of 63 W CFL (compact fluorescent light bulb): an average wattage of 15.3 W
Brown appliances	Televisions, VCRs (video cassette recorders), non-portable audio equipment: hi-fi systems, record players etc. satellite control boxes for TVs, cable control boxes for TVs, portable audio equipment: cassette recorders, radios, clock radios, X-boxes (games etc.)
Miscellaneous appliances	Irons: steam irons and dry irons, vacuum cleaners, DIY equipment: drills, torches, battery chargers, garden equipment: lawn mowers, trimmers, hedge trimmers, other home care equipment: sewing machines, floor polishers, lights on extension cords, hair styling equipment: hair dryers, curling tongs small personal care appliances: electric toothbrushes, electric razors, electric towel rails, electric blankets, electric instantaneous showers, central heating pumps, personal computers, computer printers, slide projectors, electric typewriters etc.

3. Domestic end-use electricity consumption

Total electrical energy consumed is aggregated individual appliances power consumption. Domestic appliances are divided into different groups; cold and wet appliances, brown appliances, cooking and lighting and miscellaneous appliances [8]. Table 1 shows the domestic electrical appliances and Fig. 4 corresponds to total electricity consumed by domestic appliances in million tones of oil [9].

Each household depending on factors influencing on overall power consumption has different load profile. These factors known as behavioural factors included: geographical location of houses, socio-economic factor includes employment, age, education, size and type of the houses, number of occupants etc. Mansouri et al. in [8] has demonstrated these behavioural factors which change the load profile in the UK. Ownership rate is the total number of appliances divided by the number of households owning at least one of each device. Ownership level of different domestic appliances in the UK in typical is shown in Fig. 5 [9]. This graph indicates that on average most of the domestic consumers in the UK own at least one “Iron”, however this may change for a household with 9 members living together.

The general equation to calculate the total daily power demand that is applicable to all end-use appliances is:

$$D_{it} = N_i \times C_i \times F_{it} \quad (1)$$

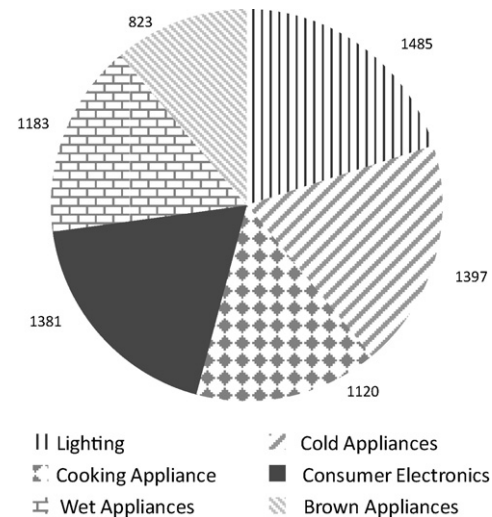


Fig. 4. Domestic end-use electricity consumption in 2005 (million tonnes of oil equivalent).

$$E_i = \alpha \cdot \sum_{t=0:00}^{t=23:59} D_{it} \quad (2)$$

where D_{it} is total power required by component i at time t ; N_i is the number of appliances of type i ; C_i is load type i energy consumption (watt); F_{it} is the fraction of the connected load of type i in at time t ; E_i is the daily energy consumption of load type i .

As F_{it} in particular for domestic sector depend on type of day (weekday, Saturday, Sunday) another coefficient “ α ” needs to be multiplied to Eq. (2) in order to differentiate the energy consumption of each appliance in different days. Besides, N_i which represents the number of appliances of type i depends of socio-economic situation of each household. Therefore a comprehensive aggregated demand requires considering these modules as well.

Time-of-use tariff programs change the mode of operation of domestic electrical appliances; they mainly influence on space heating and water heating as shifting the time of operation of these two end-use appliances does not cause inconvenience and overall satisfaction of consumers is not affected. Figs. 6 and 7 show the end-use power consumption in domestic unrestricted and domestic Economy 7.

4. Responsive demand

Responsive demand (dynamic demand) refers to the reduction of customer energy usage at times of peak usage or contingency in order to help address system reliability, reflect market condi-

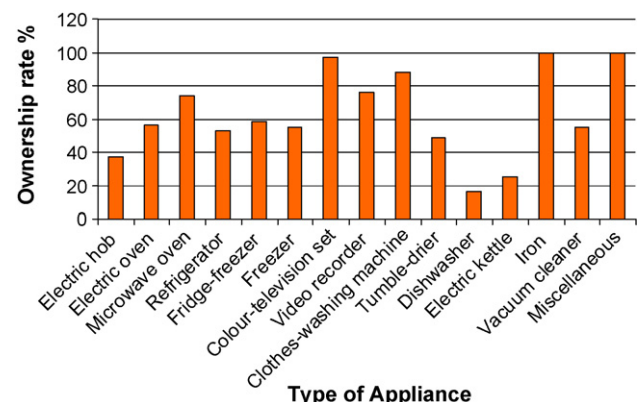


Fig. 5. Ownership rate of domestic appliances.

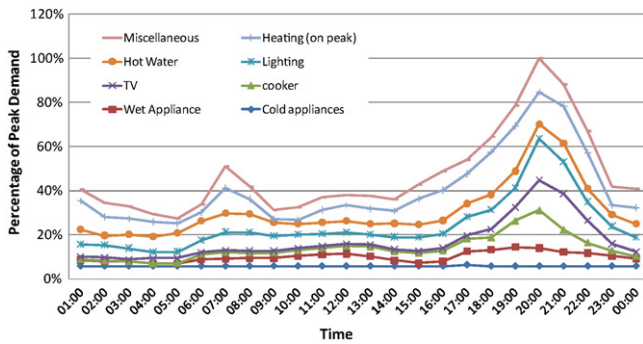


Fig. 6. Domestic non-restricted end-use power consumption.

tions and pricing, and support optimization or deferral. Demand response programs may also include dynamic pricing/tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling. Responsive demand as one of the DSM programmes has been used in power system since 1960s where ripple controllers had been installed with the intention of reducing the energy consumption of water heating units as one of the direct load management methods [10]. Recently new type of responsive demand has been introduced to provide ancillary services such as spinning reserve.

There are two major categories of responsive demand [11]:

1. Price-based demand; such as response real-time pricing (RTP), critical-peak pricing (CPP) and time-of-use (TOU) tariffs, give customers time-varying rates that reflect the value and cost of electricity in different time periods.
2. Incentive-based demand response programs pay participating customers to reduce their loads at times requested by the program sponsor, triggered either by a grid reliability problem or high electricity prices.

To evaluate the amount of load which could become responsive it is important to know the load profile of the proposed consumer. If load are to become responsive like load shifting programs the overall satisfaction of consumers should not be affected, therefore only those loads may become responsive which have more elasticity and may be shed in response to network operator or even autonomously by detecting the network variations. These loads named “Passive Loads” may include heating, wet and cold appliances.

Depending on the tariff method which customers are being billed the amount of responsiveness varies. Fig. 8 shows the amount of available load which could become responsiveness in percentage of total demand at each hour.

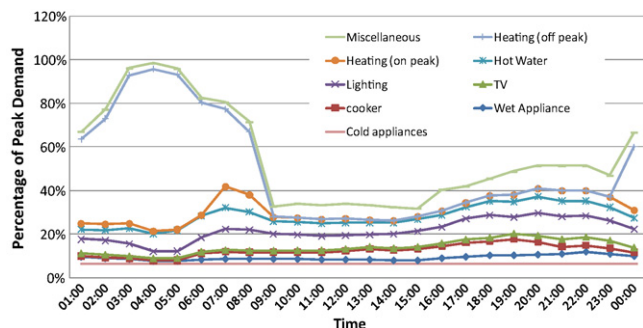


Fig. 7. Domestic Economy 7 end-use power consumption.

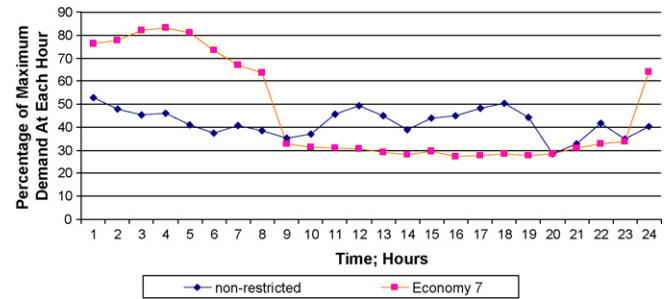


Fig. 8. Available load with responsiveness capability.

5. Numerical example in domestic sector

This paper aims to show how in a network with different load tariffs, the level of responsiveness may change. The proposed network is a small area in the city of Bath; in the Southwest of the UK. The area which has been studied is mainly residential including a major educational centre which includes halls of residence. In Table 2 the area's data has been demonstrated [12]. Our study to calculate the level of responsiveness has only considered the domestic sector of this area despite the fact that industrial and commercial consumers may have also opportunity to make some of their loads responsive.

To calculate the total demand it is important to distinguish two different load tariffs as total level of responsiveness is different in each case, sum of responsiveness level is quantifies by multiplying number of meters which represent Economy 7 tariff consumers by the responsiveness level of this profile, plus multiplying number of meters which represent non-restricted consumers by the responsiveness level of this profile and divide it by total number of domestic consumers:

$$RD_t = \frac{(Nn_t \times rn_t) + (Ne_t \times re_t)}{NT} \quad (3)$$

where RD_t is total level of responsiveness at time t ; Nn_t is the number of non-restricted consumers; Ne_t is the number of Economy 7 consumers; rn_t is the level of responsiveness for non-restricted consumer at time t ; re_t is the level of responsiveness for Economy 7 consumer at time t ; NT is total number of domestic consumer. Fig. 9 shows the total level of responsiveness in this area among domestic loads.

It is observable from Fig. 9 that responsiveness level does not necessarily correspond to the overall demand level at different times. In fact, it is dependent on different types of appliances which are used. Total responsiveness level over night is higher compare with other times, since major electrical appliances at these times are night storage heaters, and fridges which both can become responsive.

Such information can be used by different utilities. An electricity supplier can contract domestic demand response to lessen the need for purchasing the electricity at high prices from the market, and in return offer incentives to the domestic participants. A distribution network operator may also contract domestic demand response to minimize the stress on distribution networks by reducing the sudden increase in demand, and in the long-term it may alleviate

Table 2

Bath and North East Somerset Area Middle Super Output Are (SOA) 12 data.

Total population	9435
Number of households	3459
Number of non-restricted domestic meters	3267
Number of domestic Economy 7 meters	625
Number of industrial/commercial meters	434

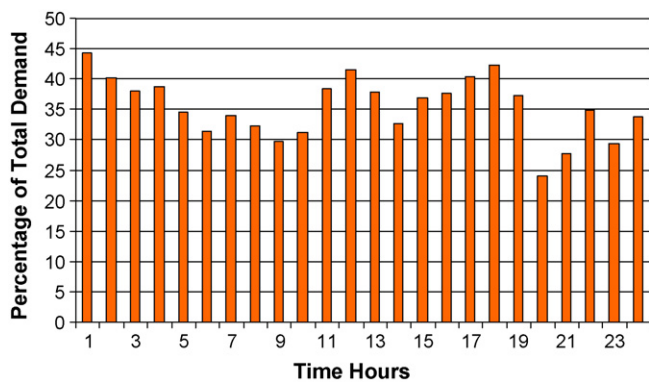


Fig. 9. Total level of responsiveness.

the need for network reinforcement as a result of demand growth. If domestic demand response is offered to large number of consumers, this could benefit the network operator in balancing the demand and supply process. In contingencies such as losing a generator, or fault on a transmission line, dispatch pattern and power transit from different zones will have to be changed to maintain the stability of the system. In many occasions load shedding occurs as network or generators are unable to supply the current demand level. Since domestic demand response can be used instantly and is available at different zones, maintaining demand-supply balance will be possible through reducing the demand from a group of domestic consumers while the interruption in the overall service will be minimized.

6. Conclusions

Responsive demand is currently providing variety of services for power systems. Demand response as a product is either utilized as a reliability based product, or for economical purposes. In both cases, information regarding the concentration, location and capacity of available demand response is required. This technology has been employed in many power systems across the world, and industrial loads are the major participants. Domestic consumers have not benefited from this technology, neither the network, as quantifying the level of responsiveness for domestic consumers requires performing load profile assessment for individual customers and aggregate the total load profile of a group of consumers.

As domestic demand level for individual consumers is very small compare with large industrial loads, such assessment requires having generic load profiles of different appliances so the calculations are simpler. This paper proposed a generic approach to quantifying the level of responsiveness among domestic consumers. Load profile of different appliances owned by a group of consumers are derived and depending on their electricity tariff which influences the operation pattern of different appliances, total load profile is modelled. It was shown that demand response can be provided by certain types of domestic appliances. Hence, it is required to study those appliances to see what proportion of demand can become responsive.

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